NHDOT SPR2 PROGRAM
RESEARCH PROGRESS REPORT

INSTRUCTIONS:

Project Managers and/or research project investigators should complete a progress report at least every three months during the project duration. Reports are due the 5th of the month following the end of the quarter. Please provide a project update even if no work was done during this reporting period.

Project # 26962G	**Report Period** Year: 2018 ☐Q1 (Jan-Mar) XQ2 (Apr-Jun) ☐Q3 (Jul-Sep) ☐Q4 (Oct-Dec)	
Project Title: The Living Bridge: A Benchmark for Bridge Monitoring The Living Bridge: Tidal Turbine Deployment System		
Project Investigator: Erin S. Bell Project Co-Investigators: Martin Wosnik, Kenneth Baldwin **Phone: (603)862-3850** **E-mail: erin.bell@unh.edu**		
Research Start Date: sample July 1, 2016	**Research End Date:** May 30, 2019	**Project schedule status:** ☐ On schedule ☐ Ahead of schedule X Behind schedule

Brief Project Description:

This project is a collaborative project between the civil and environmental engineering, mechanical and ocean engineering programs at UNH, the NHDOT and several industrial partners to install of an array of structural health monitoring, environmental and estuarine sensors on the Memorial Bridge in Portsmouth, New Hampshire that will be powered by a tidal turbine attached to one of the bridge piers. The funding for the Tidal Turbine Deployment System is leveraged with funding provided by the National Science Foundation's Partnerships for Innovation (PFI) Program, The Living Bridge: The Future of Smart, Sustainable User-Centered Transportation Infrastructure.

Progress this Quarter (include meetings, installations, equipment purchases, significant progress, etc.):

Benchmark for Bridge Monitoring:

The final instrumentation plan for the structural health monitoring was discussed at the June 28th 2016 technical advisory group meeting in Concord, NH, and was approved on July 18 2016. The structural sensors were installed on the bridge structure in March 2017. The installation was complete on March 8 2017. The sensors are operational. The marine sensors are installed on the turbine support platform and the collected data is integrated with the structural information, mechanical performance information and environmental information. The structural sensors on the vertical guide posts were installed in late October 2017. These sensors are temporary collecting data followed by the installation of the tidal turbine in June 2018. The sensors will be permanently installed to the database when the droop cable is installed to the main connector.

A pseudo-static load test was conducted on October 27th 2017. This load test used a NHDOT truck loaded with concrete barriers. The test location was the Portsmouth side of the bridge. A NHDOT truck carrying Jersey barriers was used. A total of five runs (5 mph) were conducted: three (3) runs on the northbound side and two runs on the southbound side. Each static run included two stops. In addition, five dynamic runs (15-30 mph) were conducted: two runs without traffic (one on the northbound side and one on the southbound side) and three runs with traffic (two on the northbound side and one on the southbound side). This collected data is being used to validate the multi-scale structural models of the Memorial Bridge.

Progress in FE modeling;

A set of full-scale and multi-scale finite element models of the bridge was developed at UNH in Lusas® by PHD canidade Maryam Mashayekhizadeh. This program was chosen to mirror the modeling done during bridge design by HNTB. Also, The structural model of the Memorial Bridge in SAP2000® is complete. A comparison of Lusas® models with the SAP® model is shown that they are in good agreement with each other in preparation for calibration with collected field data from the October 2017 load test.

The models are for the Portsmouth span and lift tower only. The models are being validated with respect to the collected data specifically focusing on stiffness of the connection elements. The developed multi-scale FE models of the bridge

calibrated using the field data during the load test are going to be applied to inform the health status of the critical locations which are in reasonable distance to the sensors. The models are well-detailed to inform the most critical locations which may not be all captured using the field data. In April 2018, Maryam did presentation in Structure Congress, Fort Worth, TX on "Multi-scale Finite Element Model Development for Long-Term Condition Assessment of Vertical Lift Bridge. She also on presented "Data Validated Multi-Scale Finite Element Modeling Protocol for Complex Connections of a Movable Bridge" in June 2018 in Engineering Mechanics Institute Conference, MIT.

A detailed model of the gusset-less truss connection in ABAQUS® is completed. The response from this model is the basis for a quantitative set of stiffness values (stiffness matrix) to represent the connection in the structural SAP® model. This model was manually verified with respect to the collected data and the analytical responses from this model will be to determine the stiffness value of the super-element that will represent the gusset-less connection in the SAP2000® model.

Graduate student, Timothy Nash, conducted a study of wind loads developed from AASHTO, ASCE7-10 and European codes to predict the structural response of the lift tower. Tim defended his thesis and graduated with his masters degree in December 2016. In May 2018, part of his results is presented by Milad Mehrkash, PhD candidate, in the Engineering Mechanics Institute (EMI) conference in Boston, MA. A journal paper on this work will be submitted in August 2018. This predicted information will be compared to the measured structural response of the tower, as a data set is collected over time under varying environmental conditions.

Graduate student, Chao Yang, conducted a probability-based environmental demand assessment of the wind and wave loads on the tidal turbine deployment platform, specifically with respect to the anchorage capacity. Chao defended his thesis and graduate with his masters' degree in December 2017. In May 2018, part of his results is presented by Vahid Shahsavari, postdoctoral research scholar, in the Engineering Mechanics Institute (EMI) conference in Boston, MA. A journal paper is planned for submission in September 2018.

PI Bell continues to communicate with bridge designer, Ted Zoli, both in live and virtual meetings. The last conference call as held in April 2018 with Professor Ricardo Medina to discuss this project and program 26962M. The most recent live meeting was a live meeting in New York on November 22nd 2017. We are planning a conference call in July 2018 to discuss this and project 26962M.

Progress of Fatigue assessment of the critical components at the Memorial Bridge

Doctoral candidate, Maryam Mashayekhizadeh, has performed fatigue assessment of the critical gusset-less connection at the Memorial Bridge using the long-term high-speed monitoring data to determine the remaining life of the bridge's components. The most critical areas showing less remaining life can be identified for further inspection and maintenance activities. It is planned to characterize the monitoring data into the meaningful categories including the structural and environmental impacts to determine the most deteriorative factors that can threaten the remaining life of the gusset-less connection for the further bridge's management programs. Also, the remaining life of the non-instrumented critical components of the bridge will be determined using the analytical response of the FE models.

Progress of model updating, parameter estimation and condition assessment of the Memorial Bridge;

PhD candidate, Milad Mehrkash, developed an API MATLAB-based code to estimate the stiffness parameters of structures. At this step, this code can be used for updating the small-scale structures. However, it is in progress to be able to update stiffness parameters of the gusset-less connection of the Memorial Bridge at the end of the project. Also, the potential structural damage to the gusset-less connection of the Memorial Bridge will be simulated in ABAQUS® model of the connection and LUSAS® model of the bridge, and the capability and robustness of the SAP2000® model updating procedure for the damage detection, localization and identification will be verified. Milad and Vahid developed a modal system identification program in MATLAB for extraction of the Memorial Bridge modal parameters from the monitoring data. In May 2018, Milad presented the results of this study in the Engineering Mechanics Institute (EMI) conference in Cambridge, MA. Milad's abstract about local model updating of the Memorial Bridge gussetless connection was accepted to be presented in SMT & NDT-CE 2018 conference which will be held in New Brunswick, NJ in September.

Doctoral candidate, Maryam Mashayekhizadeh, has performed fatigue assessment of the critical gusset-less connection at the Memorial Bridge using the long-term high-speed monitoring data to determine the remaining life of the bridge's components. The most critical areas showing less remaining life can be identified for further inspection and maintenance activities. It is also planned to characterize the monitoring data into the meaningful categories including the structural and environmental impacts to determine the most deteriorative factors that can threaten the remaining life of the gusset-less connection for the further bridge's management programs. A series of Multi-Scale Finite element models of the Memorial

Bridge was developed in LUSAS ® to acquire the most efficient model in terms of accuracy as well as computational time. The developed multi-scale FE models of the bridge calibrated using the field data during the load test are going to be applied to inform the health status of the critical locations which are in reasonable distance to the sensors. The models are well-detailed to inform the most critical locations which may not be all captured using the field data. Also, the remaining life of the non-instrumented critical components of the bridge will be determined using the analytical response of the FE models.

Postdoctoral research scholar, Vahid Shahsavari, developed an objective decision-making protocol for future condition assessment of the Memorial Bridge. The focus of this research is on long-term monitoring of the bridge behavior to train a baseline model in the early age of the bridge when the condition is undamaged. In January 2018, Vahid presented the preliminary results of his findings at the 97th Annual Meeting of Transportation Research Board (TRB), Washington D.C. The proof of concept is analytically verified to detect the change in structural performance due to abnormal events using finite element model of the Memorial Bridge in SAP2000®, resulting in a conference paper at the 27th American Society for Nondestructive Testing (ASNT) Research Symposium, Orlando, FL, presented by Vahid. In the last three months, Vahid and Milad collaborated on this subject and proposed a new approach to predict as accurately and efficiently as possible the degraded load carrying capacity of the bridge using the calibrated analytical model of the bridge in SAP2000®. A journal paper will be submitted on this topic by the first mid of July 2018. In June 2018, Vahid and Milad submitted an abstract to the ASNT Annual Conference, which will take place in Houston, TX, October 2018. The topic of this conference paper will be about the effect of simulated damaged members on performance degradation of the Memorial Bridge, which will help to determine the critical locations vulnerable to damage along the superstructure.

List of submissions and presentations:

- Milad Mehrkash and Erin Santini-Bell, Local Condition Assessment and Damage Detection of Gusset-less connections Used in a Vertical Lift Truss Bridge, 9th International Conference on Structural Health Monitoring of Intelligent Infrastructure, St. Louis , MO, 2019 (abstract is under review).
- Milad Mehrkash and Erin Santini-Bell, Local Condition Assessment and Damage Detection of Gusset-less connections Used in a Vertical Lift Truss Bridge, 9th International Conference on Structural Health Monitoring of Intelligent Infrastructure, St. Louis , MO, 2019 (abstract is under review).
- Milad Mehrkash and Erin Santini-Bell, System Identification of a Bridge Gusset-less Connection by Simplified and Detailed Local Analytical Models, NDE/NDT for Highway and Bridges: Structural Materials Technology (SMT 2018) and the International Symposium Non-Destructive Testing in Civil Engineering (NDT-CE 2018), New Brunswick, NJ, 2018.
- Milad Mehrkash, Vahid Shahsavari and Erin Santini-Bell, Instrumentation Sufficiency of a Vertical Lift Bridge for Modal System Identification by Frequency Domain Analysis, Engineering Mechanics Institute Conference, Cambridge, MA, 2018
- Maryam Mashayekhizadeh, Erin Bell “Data Validated Multi-Scale Finite Element Modeling Protocol for Complex Connections of a Movable Bridge”, Engineering Mechanics Institute Conference, Cambridge, MA, 2018
- Timothy Nash, Erin Santini-Bell, Milad Mehrkash and Vahid Shahsavari, “An Objective Decision Making Protocol for Lift Bridge Operation Subjected to High Wind Loads”, Engineering Mechanics Institute Conference, Boston, MA, 2018.
- Chao Yang, Erin Santini-Bell, Vahid Shahsavari and Milad Mehrkash, “Probability-Based Demand Evaluation of the Bridge Tidal Turbine Deployment System Subject to Environmental Events”, Engineering Mechanics Institute Conference, Boston, MA, 2018.
- Maryam Mashayekhizadeh, Milad Mehrkhash, Vahid Shahsavari, Erin Bell, “Multi-Scale Finite Element Model Development for Condition Assessment of Vertical Lift Bridge”, ASCE Structures Congress 2018, Fort Worth, TX, April 19-21, 2018.
- Milad Mehrkash and Erin Santini-Bell, “Modeling and Characterization of Complicated Connections in Structural and Mechanical Systems as Applied to a Gusset-less truss connection”, 97th Annual Meeting of Transportation Research Board (TRB), Washington D.C, 2018.
- Maryam Mashayekhizdeh and Erin Santini-Bell, “Influence of temperature on vibration-based structural health monitoring of a vertical bridge”, 27th ASNT Research Symposium, Orlando, FL, 2018.
- Vahid Shahsavari, Milad Mehrkash and Erin Santini-Bell, “Structural Health Monitoring of a Vertical Lift Bridge Using Vibration Data”, 27th ASNT Research Symposium, Orlando, FL, 2018.

- Vahid Shahsavari, "Long-Term Monitoring of Bridges under Operational and Environmental Variations", The Transportation Research Board (TRB) 97th Annual Meeting, Washington, D.C., January 7-11, 2018.

Tidal Turbine Deployment System

The tidal turbine deployment system consists of vertical guide posts (VGPs) and a turbine deployment platform (TDP) on which a tidal turbine is installed and operated from.

Weekly conference calls continued with New Energy Corporation through April until the EVG-025 tidal turbine and associated power electronics were shipped on 29 May 2018. The turbine arrived at the Judd Gregg Marine Research Complex (UNH Pier) in New Castle, NH on 4 June 2018. On June 6th work began assembling and installing the turbine on the TDP at the UNH Pier. Pepperrell Cove Marine services was contracted to lift the turbine from the pier down onto the TDP using their boom truck. The turbine and its components were torqued to their rated specifications.

Figure 1 - Turbine installation at the UNH Pier.

Pepperrell Cove Marine Services also performed the lift to mount the power electronics on the TDP. By the end of the day on 6 June 2018 everything was mounted to the TDP.

In the morning, on 7 June 2018 Pepperrell Cove Marine Services towed the TDP with the EVG-025 turbine and installed it on the Memorial Bridge. When the turbine arrived at the bridge it was discovered that some of the power electronics had been slightly damaged in transit. The final hookup and repairs to the damaged electronics were made on the morning of 8 June 2018, and in the afternoon the turbine was turned on for the first time.

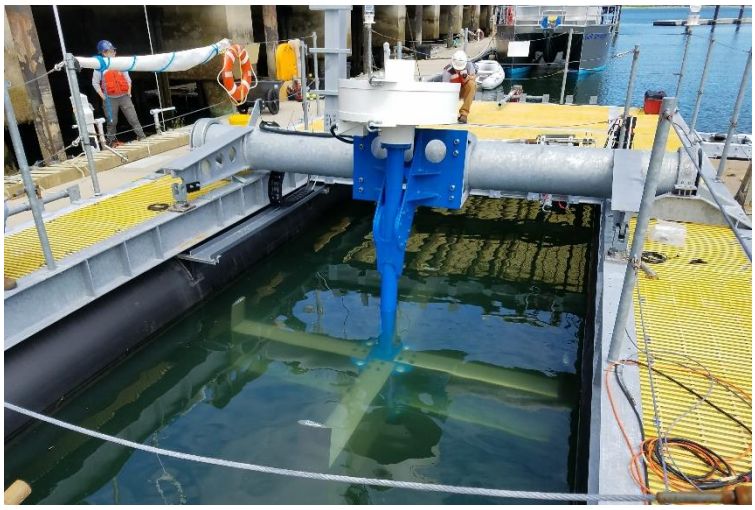

Figure 2 - (L) turbine power electronics, (R) rotor clearance check at the UNH Pier

The UNH team has spent the month of June and early July 2018 operating the turbine in an off-grid mode while the team is present. When the team leaves the TDP they remove the turbine rotor from the water. These tests are being performed to gain confidence in system operation to eventually operate the turbine in an unattended, on-grid mode.

Figure 3 - (L) Turbine installation team with all components mounted on TDP, (R) turbine operating in tidal currents

The team will be connecting the turbine to the grid soon. Along with the grid power connection, an ethernet connection will be made between the bridge and the TDP. This will enable data transfer between the estuarine instrumentation and the project database enabling real time monitoring of instrumentation measurements and turbine operation.

The Living Bridge

PI Bell presented the Living Bridge Project to the faculty at the University of Johannesburg-Auckland, South Africa during an outreach trip in July 2017 and again in June 2018

Erin Bell and Martin Wosnik presented at the New Hampshire Engineer Week in Concord in February 2018:
Bell E; Wosnik M, “The Living Bridge: Smart Infrastructure Powered by Tidal Energy”, New Hampshire Engineer Week, Concord, NH, February 2018.

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In March 2018, graduate student Ian Gagnon presented on the Living Bridge Project at the UNH Three Minute Thesis competition, practice round. Ian received 3rd place out of 18 competitors.

In April 2018, Martin Wosnik and graduate students Kaelin Chancey and Ian Gagnon presented on the Living Bridge Project at the UNH School of Marine Sciences and Ocean Engineering research symposium in Durham.

In April 2018, Kaelin Chancey presented on the Living Bridge Project at the UNH Graduate research symposium in Durham.

Martin Wosnik, Kaelin Chancey and Ian Gagnon will present on the Living Bridge Project at the Marine Energy Technology Symposium (part of Water Power Week) in Washington, DC:

> Wosnik M; Chancey K; Gagnon I; Baldwin K; Bell E (2018) The "Living Bridge" Project: Tidal Energy Conversion at an Estuarine Bridge – Deployment and First Data, Proceedings of the 6th Marine Energy Technology Symposium, METS2018, April 30-May 2, 2018, Washington, DC.

In May 2018, graduate student Kaelin Chancey presented on the Living Bridge Project at the Marine Renewable Energy Conference at the UMass Dartmouth Center for Innovation and Entrepreneurship.

In May 2018, graduate student Ian Gagnon gave his Three Minute Thesis presentation at an event titled "Seacoast Alumni Graduate School and Lifelong Learning" at the Music Hall Loft in Portsmouth.

Items needed from NHDOT (i.e., Concurrence, Sub-contract, Assignments, Samples, Testing, etc):
UNH will need access protocols for the data closet at the bridge for maintenance of the data acquisition system.

UNH would like to repeat the load test again in July/August 2018 and will require the NHDOT approval and support for the load test.

NHDOT needs to provide the owner contact for the Eversource power meter installation that can run in reverse, should the tidal turbine ever produce more power than the bridge and instrumentation can use. The maximum power output of the turbine at peak flow during spring tides was originally estimated at around 10 kW, but based on recent flow measurements could be as high as 15-20kW during short-duration "flow surges" during peak spring. This was requested by Eversource's Distributed Generation Manager, Richard Labrecque, in a phone conversation with Martin Wosnik. R. Labrecque expressed Eversource's support of the project in the conversation.

Anticipated research next 3 months:

Benchmark for Bridge Monitoring:
The integration of the structural health, mechanical operation and environmental instrumentation the sensors for remote access is complete. A trigger program has been established in March 2018 to trigger tentatively mechanical information. The proposed trigger protocol has been working efficiently so far. The event data files will be evaluated to refine the trigger limits.

The validation of the structural models of the Memorial Bridge in Lusas® as well as local model of selected gusset-less connections at the Memorial Bridge with respect to collected data in Fall 2017. Calibration of the structural models for condition and performance assessment with respect to design verification. These models have been preliminarily verified and are being used for condition assessment and operational decision making protocols.

Tidal Turbine Deployment System
The deployment of the tidal turbine deployment platform (TDP) with estuarine sensors at the Memorial Bridge occurred in June 2017. The TDP was move to the UNH Pier for installation of the pitch mechanism in late 2017. The installation of the tidal turbine on the deployment platform was completed in June 2018, with power and communication connection installed in June 2018 by NEI.

The New Energy turbine was delivered in June 2018. It was mounted to TDP and then towed to the bridge. Strain data are being collected from the sensors on the vertical guide posts. Commissioning and initial testing will be started shortly. UNH will operate this particular turbine for the duration of approximately one year as part of this project, provided operation and maintenance through the seasons prove feasible at reasonable effort and cos

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Circumstances affecting project: Describe any challenges encountered or anticipated that might affect the completion of the project within the time, scope, and budget, along with recommended solutions to those problems.

As described in the "Progress this Quarter" section of this report, the schedule delay and increased cost related to the electrical conduit negatively impact this project.

Tasks (from Work Plan)	Planned % Complete	Actual % Complete
Living Bridge: Creating a Benchmark for Bridge Monitoring		
Project Coordination	**100**	**100**
Structural Model Creation	**100**	**100**
Design the instrumentation Plan	**100**	**100**
Sensor Deployment	**100**	**100**
Data Collection and Model Calibration	**95**	**85**
Trigger Protocol	**100**	**100**
Incorporation of collected data and model into NHDOT protocols	**50**	**20**
Final Report and Adoption Recommendation	**0**	**0**
Tidal Turbine Deployment Structure		
Deployment Structure Design	**100**	**100**
Project Permitting	**100**	**100**
Installation of Support Posts	**100**	**100**
Procurement of the Turbine deployment platform	**100**	**100**
Site Installation	**100**	**100**
Electrical Connection	**100**	**90**
Final Report and Poster	**0**	**0**